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EFFECT OF LASER GLARE AND AIRCRAFT WINDSCREEN ON VISUAL SEARCH PERFORMANCE UNDER LOW AMBIENT LIGHTING

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center of the disk array on the projection screen using a fiber-optic light guide. Visual search time to locate target disks viewed through the windscreen was significantly longer compared to no windscreen and depended on the intensity of the laser produced glare. Detection of the target also depended on target location relative to the center of projected disk array. Targets near the center were more effectively hidden by the laser glare. *See also previous pages*

SUMMARY PAGE

THE PROBLEM

Naval aircrews may be exposed to laser radiation being used for a variety of purposes. Use of laser radiation as a mission deterrent is highly likely and may disrupt aircrew visual performance even at relatively low laser intensities. The purpose of this study was to determine if low intensity laser glare on and through an aircraft windscreen could disrupt visual search performance.

FINDINGS

Visual search time to locate target disks viewed under low ambient light took longer compared to laser illumination without the windscreen. Detection of the target disks also depended on their location relative to the center of the laser glare pattern. Targets near the laser light source were more effectively hidden by the laser glare, which depended on the laser intensity. Laser intensities required to produce effective glare were well below intensities necessary to produce eye damage.

RECOMMENDATIONS

The results of this experiment illustrate that low levels of laser-produced glare on aircraft windscreens can significantly disrupt visual search performed under low levels of ambient lighting. Eye protection is needed to prevent mission disruption, even at laser intensities that are not harmful to the eye.

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INTRODUCTION

Naval aircrews will likely be placed in a combat environment that is saturated with electromagnetic energy emitted from a variety of sources. Laser radiation, serving such tactical applications as countermeasures, rangefinding, and guidance will be included in this environment. Further, the use of laser radiation as a mission deterrent is highly likely and may disrupt aircrew visual performance even at intensities lower than that needed to produce eye damage.

Several other factors, including windscreen characteristics and ambient illumination, may also influence visual performance during glare produced by low-level laser irradiation. The windscreen can scatter laser light and enhance glare, while low ambient lighting can enhance retinal sensitivity and, hence, susceptibility to laser-produced glare.

The purpose of this study was to compare the effects of low-intensity laser glare with and without an aircraft windscreen on visual search performance. Flight students were seated in a passive cockpit simulator and trained to search for a target hidden in visual clutter under low ambient light. The subjects were then exposed to three levels of laser-produced glare.

MATERIALS AND METHODS

SUBJECTS

Six male student naval aviators awaiting training volunteered as subjects for this study. All subjects were 23 years old and had passed a physical exam. Their visual acuity was at least 20/15 as measured with the Armed Forces Visual Test.

EQUIPMENT

Laser and Laser Safety

A coherent light beam generated by an argon ion laser (Innova 70-2, Coherent Laser Products Division, Palo Alto, CA) was conducted by fiber optics to the center of a visual display set up in an adjacent room (Fig. 1). Laser beam intensity was reduced using beamsplitters and neutral density filters and focused on the polished end of an optical grade fiber-optic cable by a fiber-light coupler (Newport No. 714/965-5406). The fiber-optic cable (0.22-mm od) consisted of a single-strand core of acrylic polymer (0.10-mm diam) with a fluorine-polymer sheath. The distal end of the fiber-optic cable projected a 30° cone of laser light toward the cockpit and subject.

An electronic shutter (Newport No. 845) was placed in the beam path before the fiber-light coupler to control delivery of laser light to the subject. The final intensity of the laser beam (before the light coupler) was controlled using different neutral density filters to produce three intensities at eye level in the cockpit simulator with or without the windscreen in the visual path.

The laser was always operated at full output power and subsequently reduced to a desired intensity for display to the subject. An overexposure could only occur by failure of the mechanical barriers (beamsplitters and filters), which was highly unlikely as these were exposed to light intensities far below design limits. In addition, four separate laser-defeat switches were strategically located, including a defeat switch in the cockpit.

A standard operating procedure developed for this laser adhered to the ANSI Z136.1 1986 safety standard. The risk of accidental overexposure to laser light near the far end of the fiber-optic cable was prevented by mechanical barriers that blocked subject access to the projection screen. The hazard zone at the projection screen was 10 cm from the display end of the fiber-optic cable. All experiments were supervised by a naval medical officer.

Laser Power Levels and Radiometry

Laser output power was monitored constantly with a power meter (Coherent 2000) and a strip-chart recorder (Soltec model VP-6223S). Laser intensity at the subject's eye level in the cockpit was measured before each test session with a radiometer (United Detector Technology model 61) and a laser power meter (Coherent model 212). Three laser power levels were used: 0.09, 0.14 and 0.2 $\mu\text{W}/\text{cm}^2$. Mean drift (\pm SEM) in the power output of the laser over 18 exposure sessions was $2.32 \pm 0.42\%$.

Power-level values at the subject never exceeded the ANSI maximum permissible exposure (MPE) standard. The maximum time that the laser beam was projected on the subject during a visual display was 20 s. Therefore, the total time that a subject could be exposed during an experimental session was 1600 s (80 trials \times 20 s). Laser power levels, MPEs, and windscreen conditions are presented in Fig. 3.

Cockpit Simulator

An A/4 aircraft windscreen assembly was fitted to the cockpit-familiarization trainer (Fig. 3). The cockpit's center glass windscreen (22-cm wide \times 64-cm long \times 3.5-cm thick) could be removed by simply unfastening the retainer and lifting it from its cradle. Measured light transmission of the visual search task through the windscreen varied between 60 and 67% depending on location of measurement on the windscreen. Subjects were visually monitored using closed-circuit television. Voice contact was maintained with the subject at all times with a voice-actuated intercom system located near the cockpit.

VISUAL SEARCH TASK AND PHOTOMETRY

The visual-search task was a modification of that described by Cole and Jenkins (1). The task contained 80 separate displays, each composed of 119 background disks and 1 target disk (Fig. 4). The displays were constructed on a microcomputer (Zenith Z-248) and plotted on white paper using an x-y plotter (Graphtec MP-2000). Each display was then photographed on high-contrast negative film and mounted in a 35-mm cardboard slide holder.

A field extending 7.6° horizontally and 7.6° vertically was projected onto a plastic rear-projection screen (Daplex No. DA-1N, 122 \times 122 cm) 1.35 m from the subject's eye using a slide projector (Kodak Ektagraphic No. AF-2) fitted with a zoom lens (Navitar NZ-70125). An electromechanical shutter was used to control projection of each slide (Ilex Optical Co. No. 22-8437).

The background of the field was a random arrangement of disks containing a target disk, which was the smallest disk in the array. All background disks were 17.8 min arc, and the target disk was 14.0 min arc. The disks occupied approximately 14.2% of the total stimulus area; Cole and Jenkins (1) used 15%.

Two incandescent lamps (Westinghouse Soft White 75 W) were mounted behind plastic diffusing plates and behind the rear-projection screen. Contrast between the disks and the field was achieved by controlling the intensity of the lamps with a variable transformer to backlight the rear-projection screen and projected-disk images. The room housing the cockpit was illuminated by an overhead house lamp (Westinghouse Soft White 75 W), which was dimmed by a variable transformer.

The visual search task display was evaluated using a photometer (Photo Research Pritchard No. PR-1980A) and a fast spectral scanning system (Photo Research No. PR-713AM Spot Spectrascan). The overhead lamp provided a mean luminance of 0.256 cd/m² measured through the windscreen and 0.413 cd/m² without the windscreen. These were measured at the projection screen surface with a 100% reflectance standard (Photo Research RS-1). Measured through the windscreen, mean luminance (\pm SEM) of five disks projected on the viewing screen with the backlights was 4.8 ± 0.170 cd/m², and mean luminance (\pm SEM) of the field (including backlights) adjacent to each disk was 3.8 ± 0.125 cd/m². Without the windscreen, mean luminance (\pm SEM) of the disks was 8.0 ± 0.27 cd/m², and mean luminance (\pm SEM) of the adjacent background field was 5.9 ± 0.28 cd/m².

The contrast between disks and the field was 0.26 and 0.36 with and without the windscreen, respectively. A "rest" field between each display had an mean luminance of 4.0 cd/m² with the windscreen and 5.98 cd/m² without the windscreen. Other visual display characteristics are summarized in Table 1.

TABLE 1. Summary of Visual Display Characteristics.

Size of the field of view	7.6° x 7.6°
Number of disks	120
Proportion of area occupied by disks	14.2%
Size of background disks	17.8 min arc
Size of target disk	14.0 min arc
Avg. luminance with windscreen	
Disks	4.8 cd/m ²
Background field	3.8 cd/m ²
Intervening "rest" field	4.0 cd/m ²
Avg. luminance without windscreen	
Disks	8.0 cd/m ²
Background field	5.9 cd/m ²
Intervening "rest" field	6.0 cd/m ²

The color temperature of a disk near the center of the display was 2146 K with a peak spectral radiance at 1062 nm. The 1960 C.I.E. color coordinates of this disk were $u = 0.2936$ and $v = 0.3592$. The background adjacent to this disk was 1926 K with peak spectral radiance at 1066 nm and C.I.E. coordinates of $u = 0.3112$ and $v = 0.3597$.

Each display was divided into four equal quadrants by a small cross projected on the center of the screen. Each display contained a single target disk located in one of the four quadrants. The targets were located at eccentricities from the center of 0.72°, 1.44°, 2.16°, 2.63°, and 3.10° and were always placed within a quadrant at least two target diameters away from quadrant boundaries to avoid uncertainty in reporting the target quadrant.

EXPERIMENTAL CONTROL AND DATA ACQUISITION

Experimental contingencies and data collection/storage were under microcomputer control (Zenith Z-248). An analog and digital input/output board (Metrabyte Corporation model DASCON-1) and solid-state controllers (BRS/LVE, Inc.) were used to monitor response switches, advance slide projectors, control laser and slide-projector shutters, and provide audio feedback to subjects. A compiled algorithm written in BASIC source language was used for computer instructions to integrate the various experimental functions.

VISUAL ASSESSMENT

Subjects were tested before and after laser exposure to ensure that visual capabilities were not degraded. Vision assessment tests were conducted after one of the training sessions and again following (< 30 min) the first laser session using a laser intensity of 0.2 $\mu\text{W}/\text{cm}^2$. Near and far binocular central acuity at two different contrast levels, glare sensitivity, the speed of accommodation, lateral and horizontal phoria, and spatial contrast sensitivity were measured. We also measured color discrimination with the Farnsworth-Munsell 100-Hue test (Macbeth, Division of Kollmorgen Corp., Baltimore, MD).

TESTING

Seated in an airplane cockpit simulator, the subject viewed the display (119 disks) and searched for a target (1 smaller disk). Subjects reported which of four quadrants contained the target disk by depressing one of four corresponding switches mounted on their kneeboard. An experimental session contained 80 screen displays (trials) and a 1-min rest after the first 40 displays.

The subject advanced to the next trial by pressing a handheld switch. Different tones presented by a small speaker (10-cm diam) located next to the cockpit signaled right or wrong choice of quadrant for the target disk. Another tone indicated the end of a session.

Before testing, each subject received an oral briefing on the task requirements and a set of written instructions on details of the task, emphasizing both speed and accuracy in locating and reporting target location. Each subject had five training sessions on 5 consecutive days. During alternate training sessions, subjects either viewed the task through an A4-type aircraft windscreen or with the windscreen removed. The experiment used a forced-choice repeated-measures design. Each subject served as his own control.

During test sessions, laser light from the argon ion laser was projected toward the subject (30° cone) from the center of the cross-and-disk array on the projection screen using the fiber-optic light guide. In six daily test sessions, subjects viewed the display through one of three intensities of laser light adjusted to be equal with or without the windscreen in the visual path. Visual search time, post search time, and correct/incorrect quadrant choices were recorded for each trial. Post search time was defined as the time from a target quadrant choice to the subject initiating the next trial.

RESULTS

The subjects learned the visual search task very rapidly. Visual search time (VST), percentage-correct targets (PCT) identified, and session duration were essentially stable after the first session (Fig. 5). A repeated-measures analysis of variance (RMANOVA) on each variable across the five training sessions indicated that the first training session accounted for nearly all of the variance and that improvement of performance from training sessions 2 through 5 was not significant (Newman-Keuls test (NKT), $p > 0.05$). Post search time (PST) during training was also stable and averaged $0.313 (\pm 0.07SEM)$ s between trials over the last three training sessions. By the last training session, subjects were able to locate targets in the upper quadrants of the display more quickly than the lower quadrants. The mean ($\pm SEM$) VST for the two upper quadrants of the display was 742 ms shorter in duration than for the lower quadrants; upper 3.055 ± 0.233 s, lower 3.796 ± 0.248 s ($F(3, 15) = 6.15$, $p > 0.01$).

The VST averaged over trials and all eccentricities is shown in Fig. 6. The VST to locate target disks viewed through the windscreen was, at each laser intensity, significantly longer compared to VST for no windscreen (RMANOVA $F(2, 10) = 42.27$, $p < 0.05$). The no-windscreen VSTs, at each laser intensity, were not significantly different from VSTs on the last three training sessions (NKT, $p > 0.05$). Laser intensity did not have a significant effect on the VSTs averaged over all eccentricities ($p > .05$).

Session durations are shown in Fig. 7. Subjects took longer to complete laser-exposure sessions with the windscreen than no-windscreen and training sessions (RMANOVA $F(2, 10) = 75.08$, $p < .001$). The interaction between session duration and laser intensity was significant ($F(4, 20) = 2.90$, $p < 0.05$). A post-hoc comparison of the session-duration means revealed that the session durations at each laser intensity with the windscreen differed significantly from each of the no-windscreen and training sessions (NKT, $p < 0.01$).

The PCTs correctly identified are shown in Fig. 8. Subjects exposed to laser glare with or without the windscreen did not significantly differ from PCTs on the last three training sessions (RMANOVA $F(2, 10) = 1.56$, $p > 0.05$).

The VST for each target viewed through the windscreen and laser glare depended significantly on target location relative to the center of the display. This effect is shown separately for each laser intensity in Figs. 9-11. At $0.09 \mu W/cm^2$ laser exposure (Fig. 9), we observed an interaction between target eccentricity and the windscreen versus no-windscreen conditions (RMANOVA $F(8, 40) = 20.76$, $p < 0.001$). Visual search time was significantly longer at eccentricities of 0.7° and 1.4° with the windscreen compared to no-windscreen or the last training session (NKT, $p < 0.01$).

A similar interaction occurred between target eccentricity and the windscreen conditions for laser exposures at $0.14 \mu W/cm^2$ ($F(8, 40) = 22.85$, $p > 0.001$) as seen in Fig. 10. Targets at eccentricities of 0.7° , 1.4° , 2.2° , and 2.6° produced significantly longer VSTs with the windscreen than without or the last training session VSTs (NKT, $p < 0.05$).

Higher laser intensity, $0.2 \mu W/cm^2$, (Fig. 11) also showed an interaction between target eccentricity and the windscreen conditions ($F(8, 40) = 31.00$, $p < 0.001$). The VSTs for targets located at all eccentricities viewed with the windscreen were significantly different from those viewed with no-windscreen or training VSTs (NKT, $p < 0.05$). In addition, targets viewed through laser glare without the windscreen at 0.7° were significantly different from the training session VSTs at this eccentricity ($p < 0.05$).

During the last training session, subjects were able to locate targets in the upper quadrants of the display more quickly than the lower quadrants. During laser exposure sessions, however, there were no differences in VST by quadrant ($p > 0.05$).

The PSTs during laser exposure both with and without the windscreen decreased significantly from PSTs on the last three training sessions ($F(2, 10) = 10.61, p < 0.003$). There was, however, no difference in PSTs due to laser intensity ($p > 0.05$).

Finally, subjects were tested before and after laser exposure to ensure that normal vision was not altered. Subjects showed no differences before and after laser exposure on our measures of central acuity, glare sensitivity, accommodation speed, vertical or horizontal phoria, or spatial contrast sensitivity.

DISCUSSION

The effect of laser light on visual performance at intensities well below those causing eye damage has not received a great deal of attention. Our results suggest that laser light intensities far lower than the ocular-damage level may still effectively disrupt aircrew visual search performance.

This effect was observed under low ambient light levels and occurred primarily for target searches through the A4 windscreen. Without the windscreen, visual search performance approximated that of the training levels except at the highest laser intensity. In this case, laser glare without the windscreen was sufficient to obscure targets at 0.7° eccentricity.

Nevertheless, we believe that laser light scatter off of the windscreen produced a glare enhancement that effectively masked target location. This target masking, however, lasted only for the duration of laser exposure. This is noted because the percentage of targets correctly identified (Fig. 8) did not differ from training performance. Laser exposure ended after 20 s, which allowed the subject to search for the target unimpeded by the glare source. In most instances when the 20-s limit ended the exposure, subjects subsequently located the target very quickly. As evidenced by their quick PSTs of less than 1 s, subjects did not hesitate to initiate each trial. Because PSTs decreased between training and laser exposure sessions, laser intensities used here were probably not aversive to the subjects--otherwise PSTs would have increased during laser exposures.

In summary, we conclude that very low levels of laser-produced glare interact with windscreen characteristics to degrade visual search performance. The intensity of glare used in this study can easily be produced by relatively low-power lasers ($< 10 \text{ W}$) many kilometers downrange.

Laser eye protection is needed during night operations, not only to prevent eye injury, but also to preserve aircrew mission capability at laser glare intensities below damaging levels. Further research is needed to study different windscreen designs and other laser wavelengths.

REFERENCE

1. Cole B.L. and Jenkins, S.E., "The Effect of Variability of Background Elements on the Conspicuity of Objects." *Vision Review*, Vol. 24, pp. 261-270, 1984.

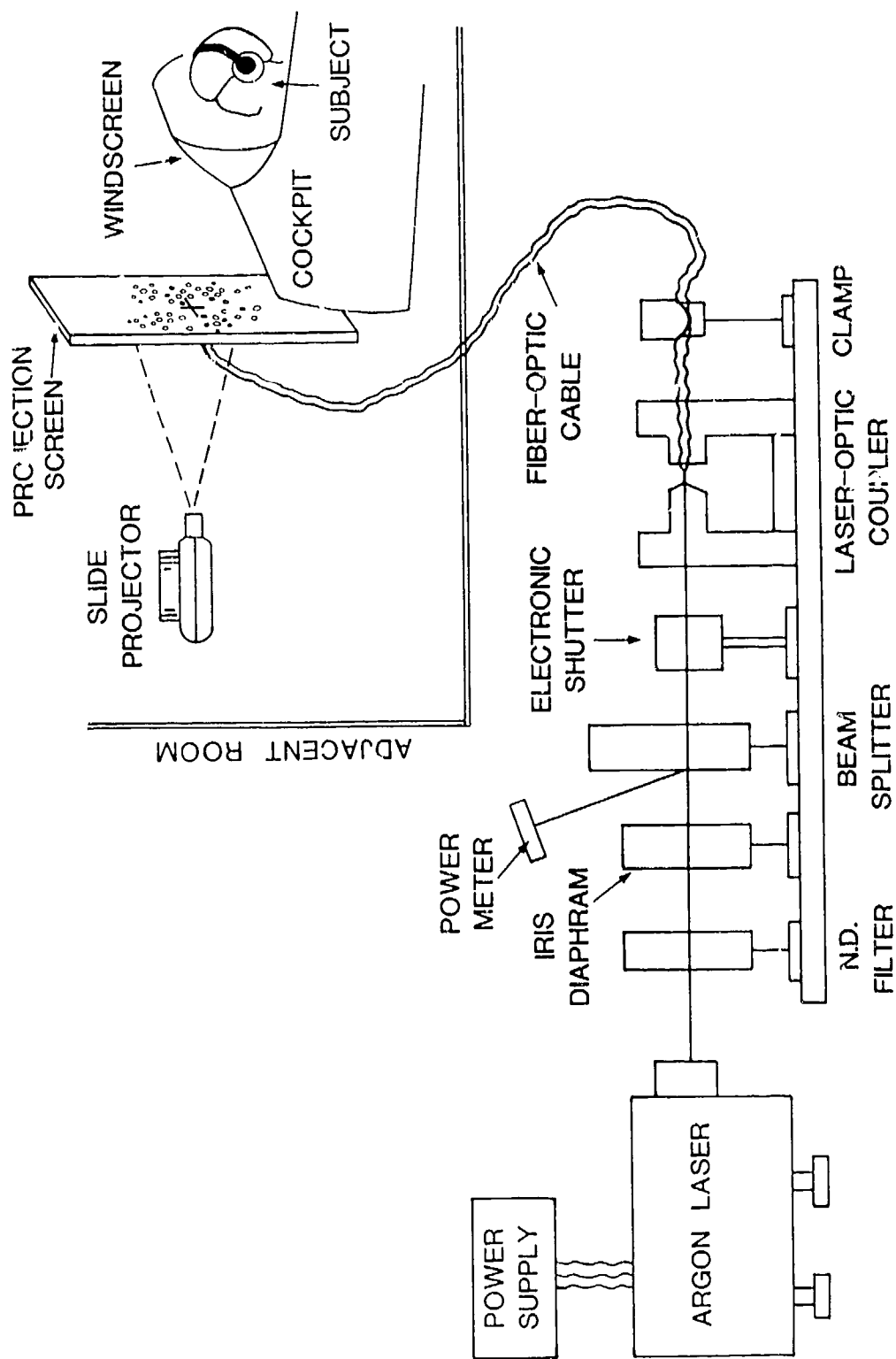


Figure 1. Schematic representation of laser and cockpit layout.



Figure 2. Subject seated in cockpit simulator behind A4 wind screen and performing the visual search task.

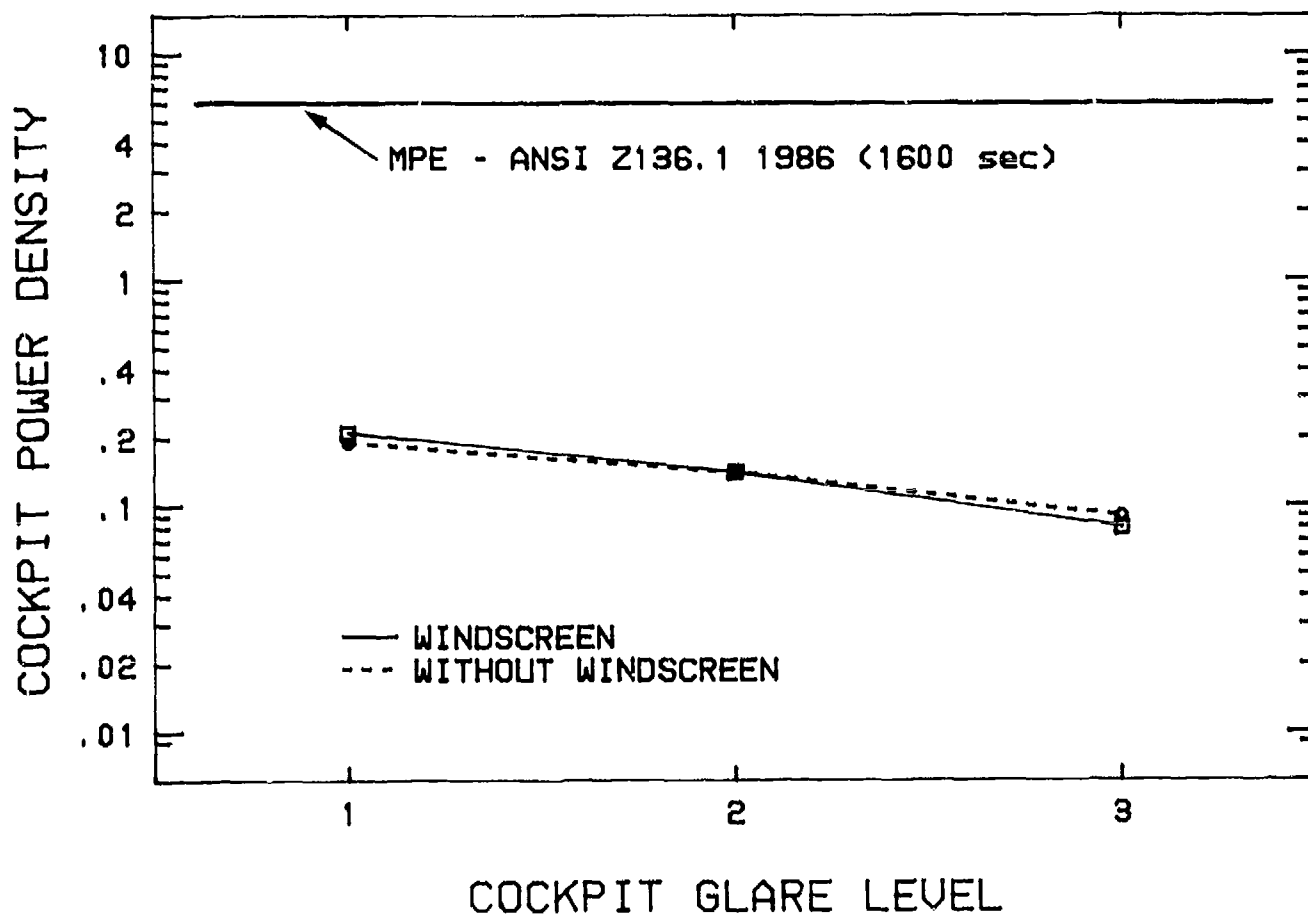


Figure 3. *Laser intensities used in this study.*

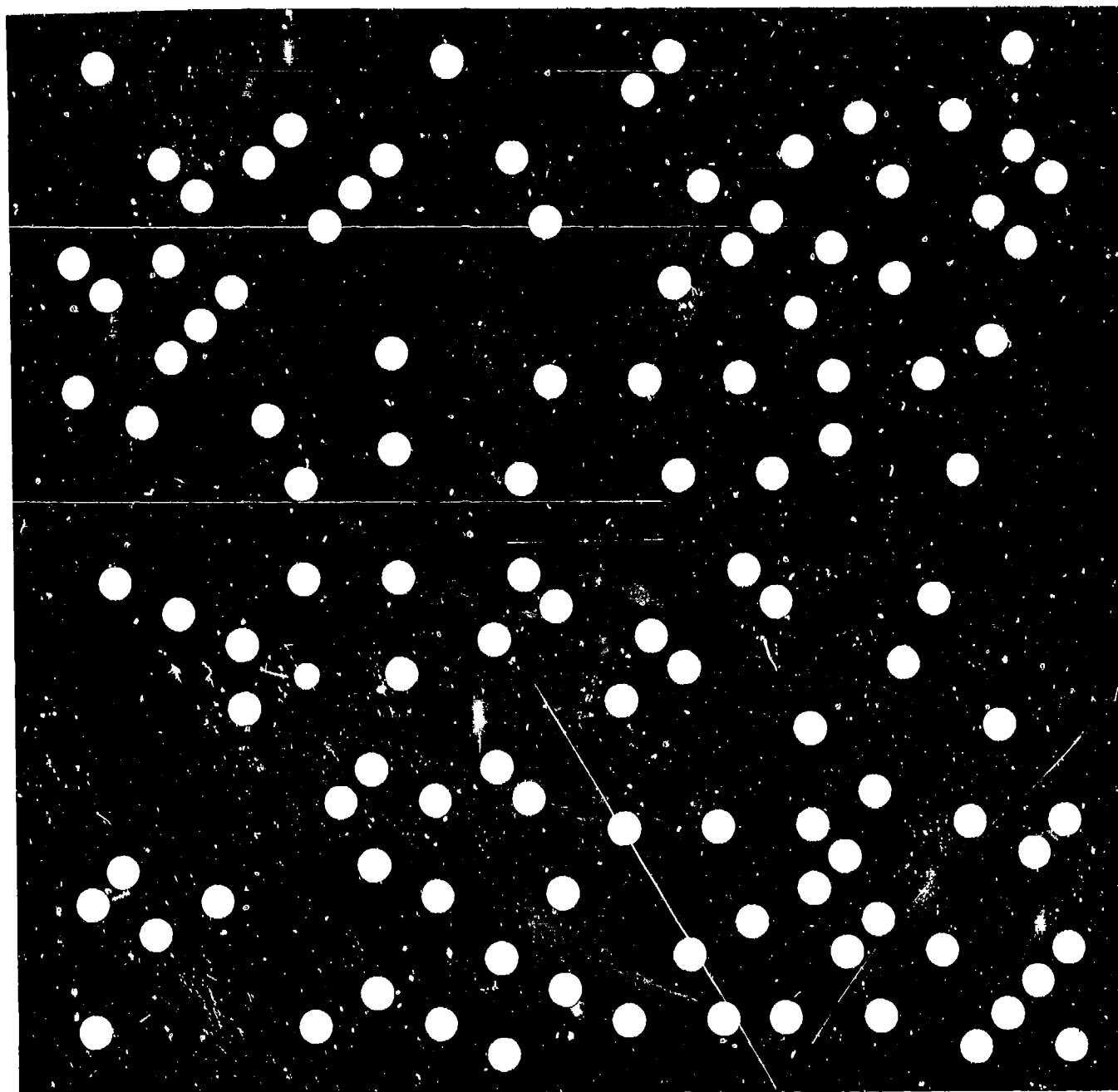


Figure 4. *Typical visual search display.*

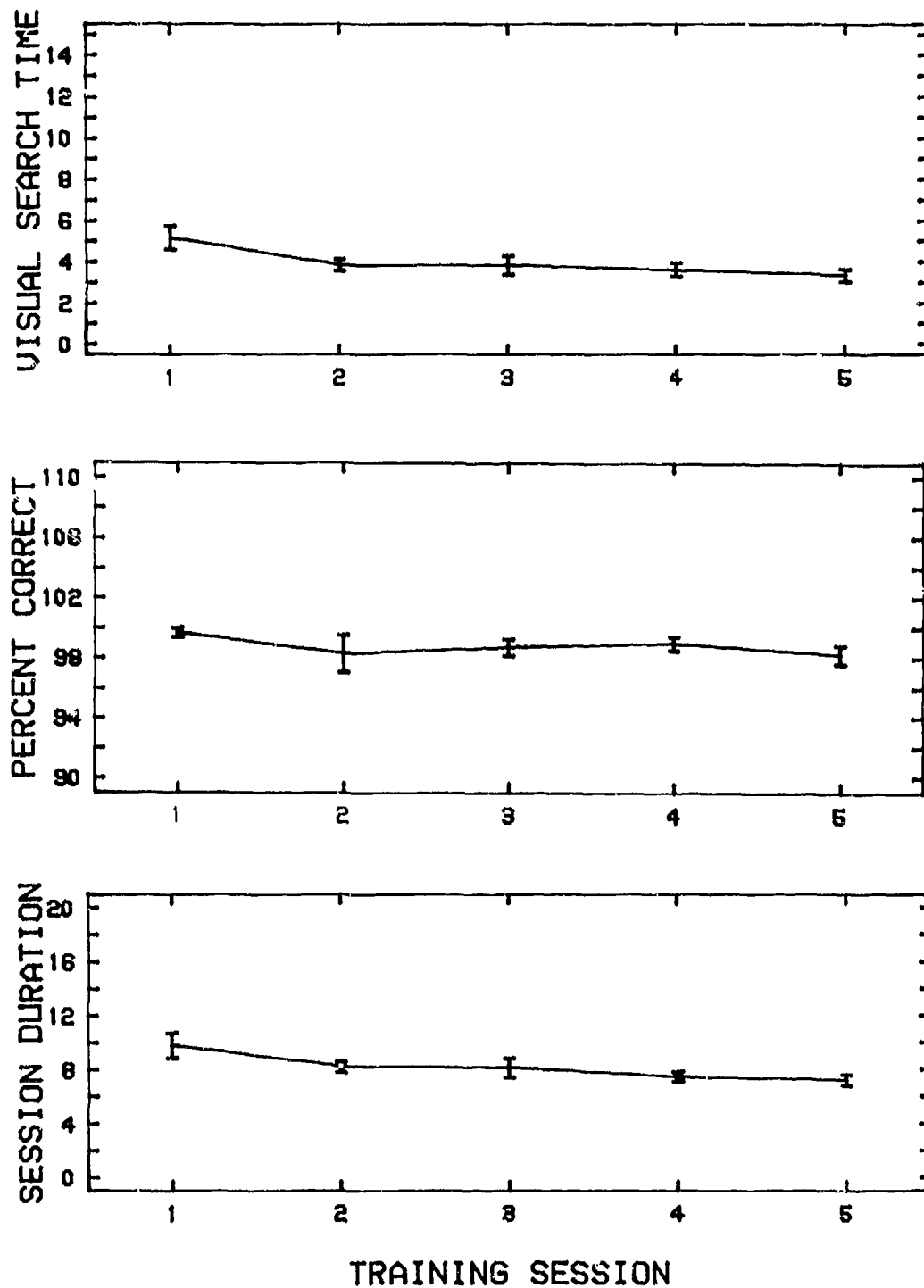


Figure 5. Mean (\pm SEM) performance on training sessions. Shown are visual search time in seconds (top panel), percentage correct targets identified (middle panel), and session in minutes to complete 80 trials (bottom panel).

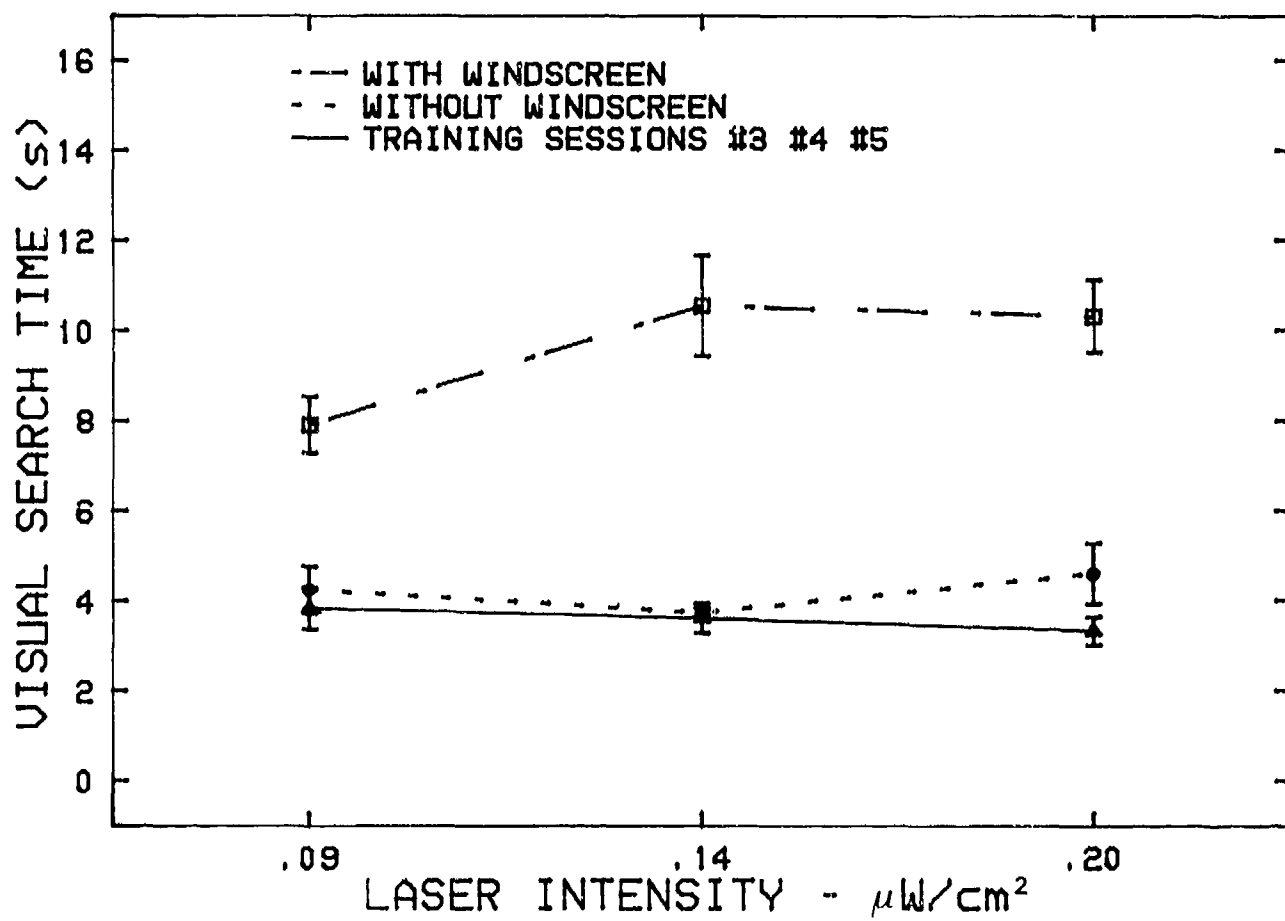


Figure 6. Mean (\pm SEM) visual search time in seconds to locate target disks.

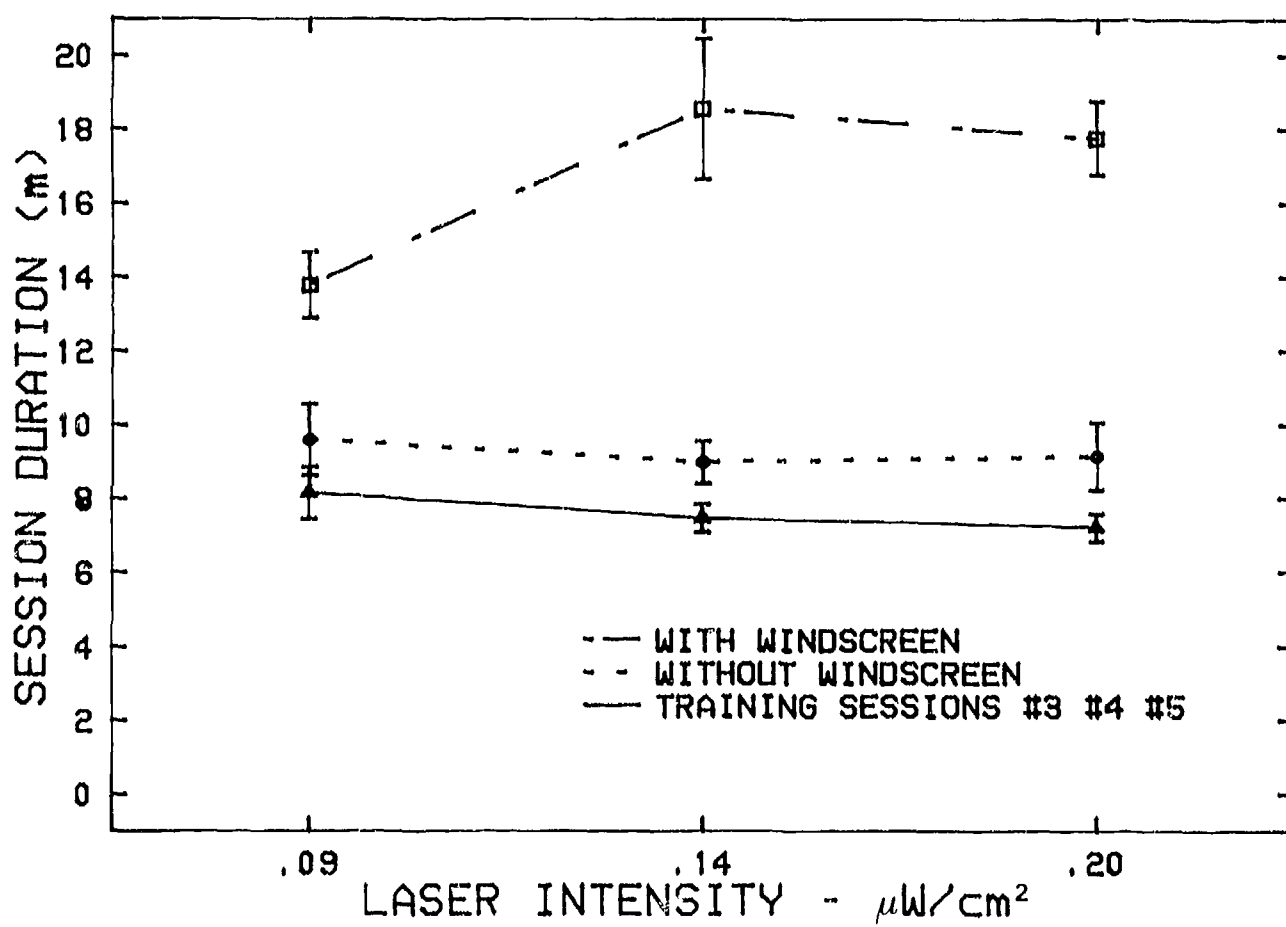


Figure 7. Mean (\pm SEM) session duration in minutes to complete 80 visual search trials.

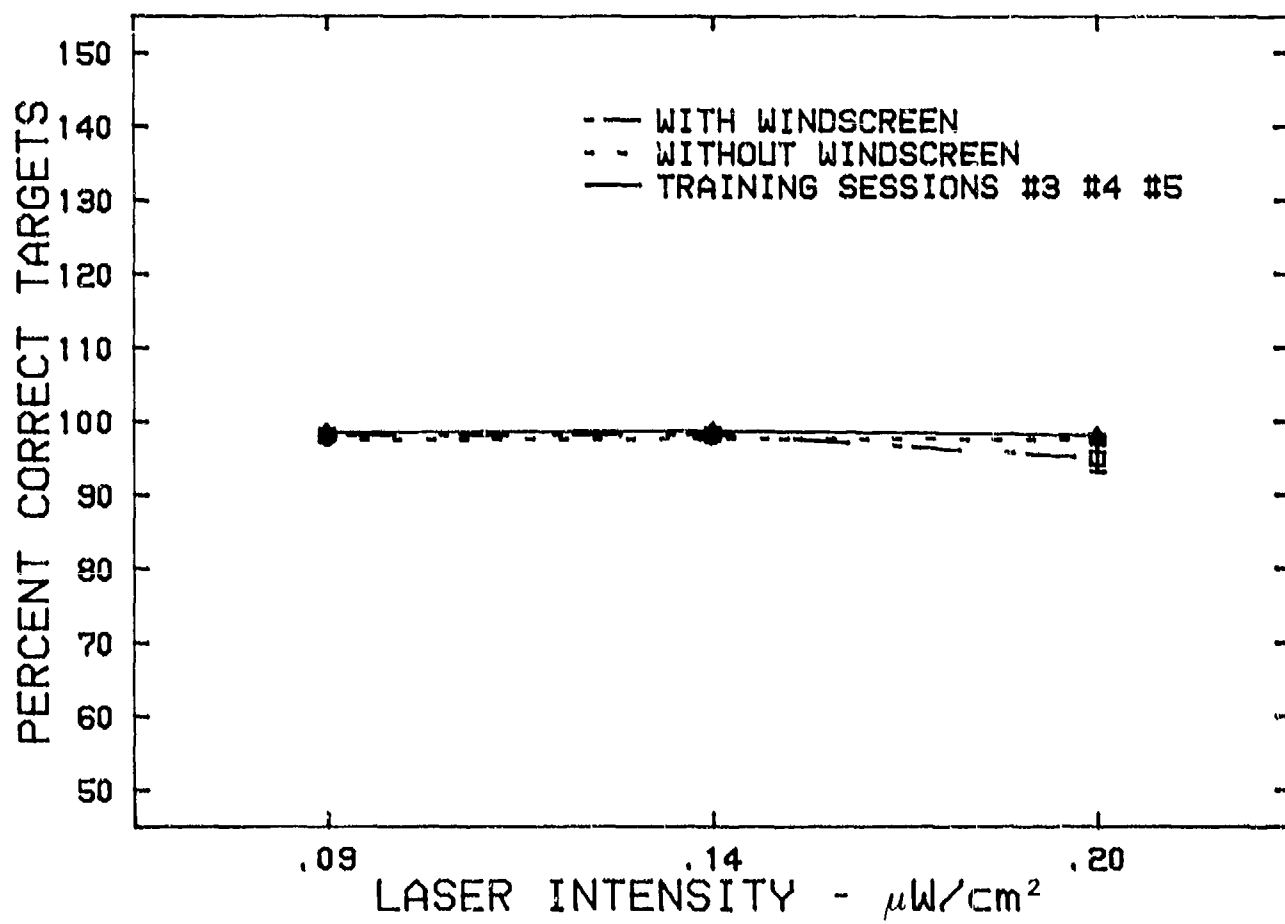


Figure 8. Mean (\pm SEM) percentage-correct targets identified.

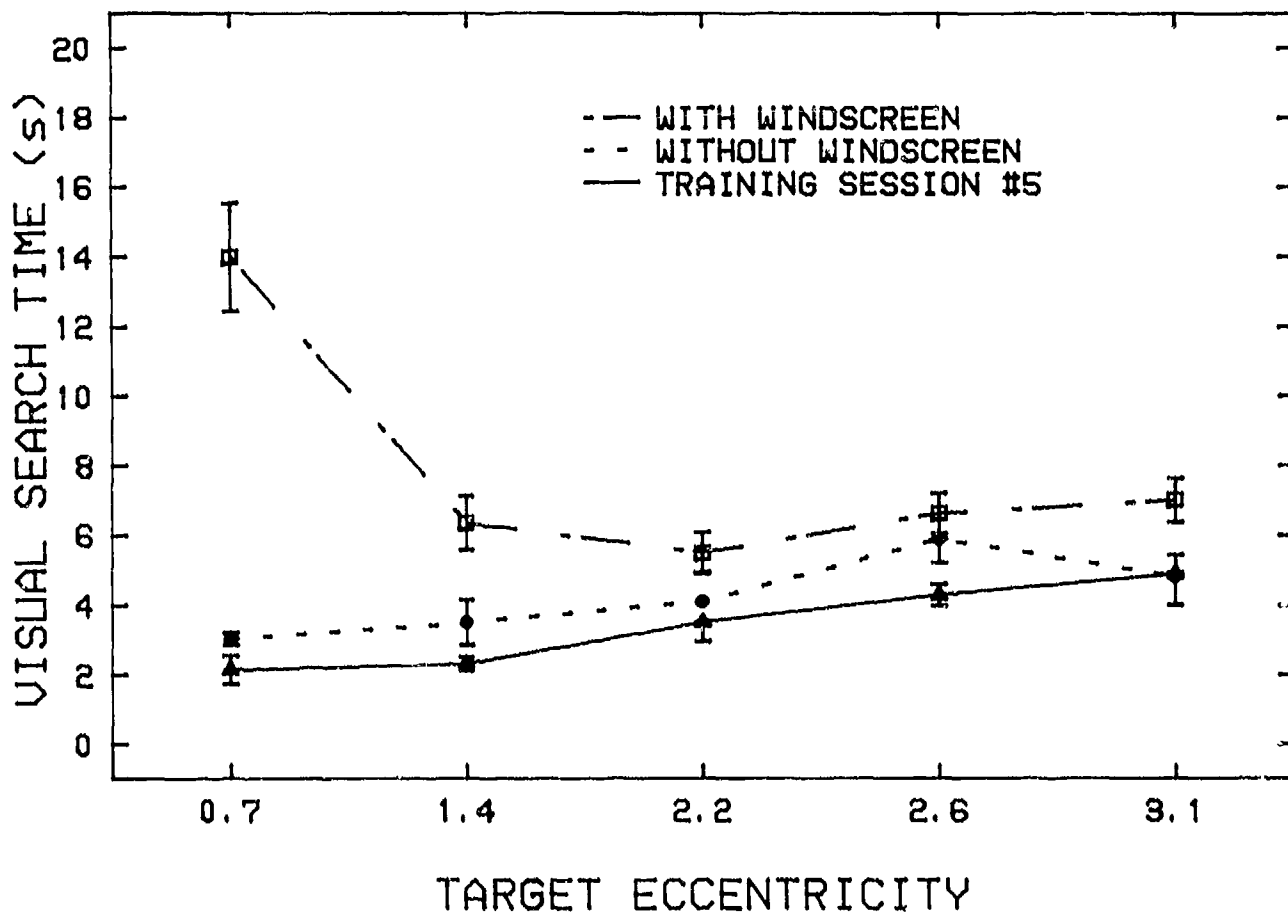


Figure 9. Mean (\pm SEM) visual search time at each target eccentricity from display center for laser exposure at $0.09 \mu\text{W}/\text{cm}^2$.

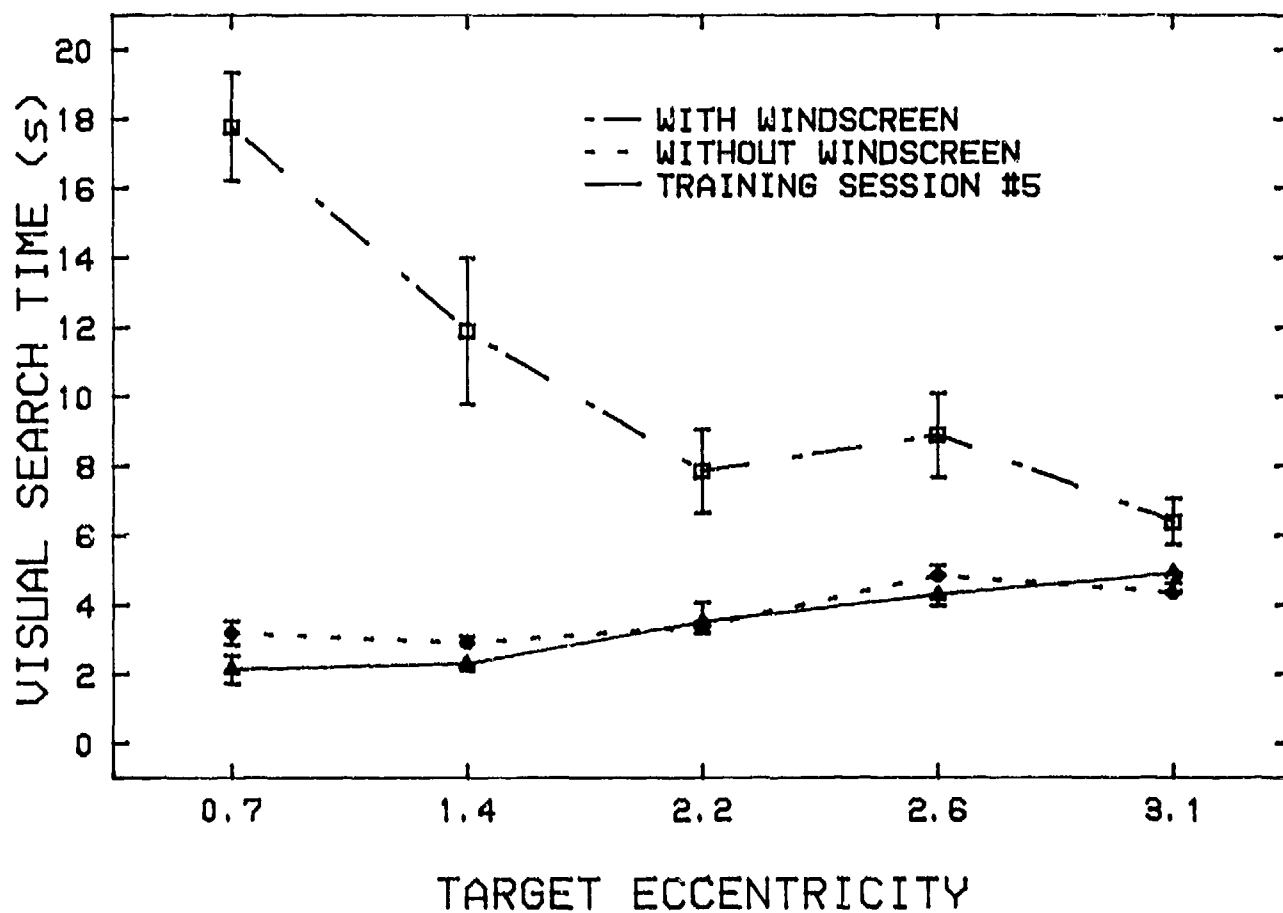


Figure 10. Mean (\pm SEM) visual search time at each target eccentricity from display center for laser exposure at $0.14 \mu\text{W}/\text{cm}^2$.

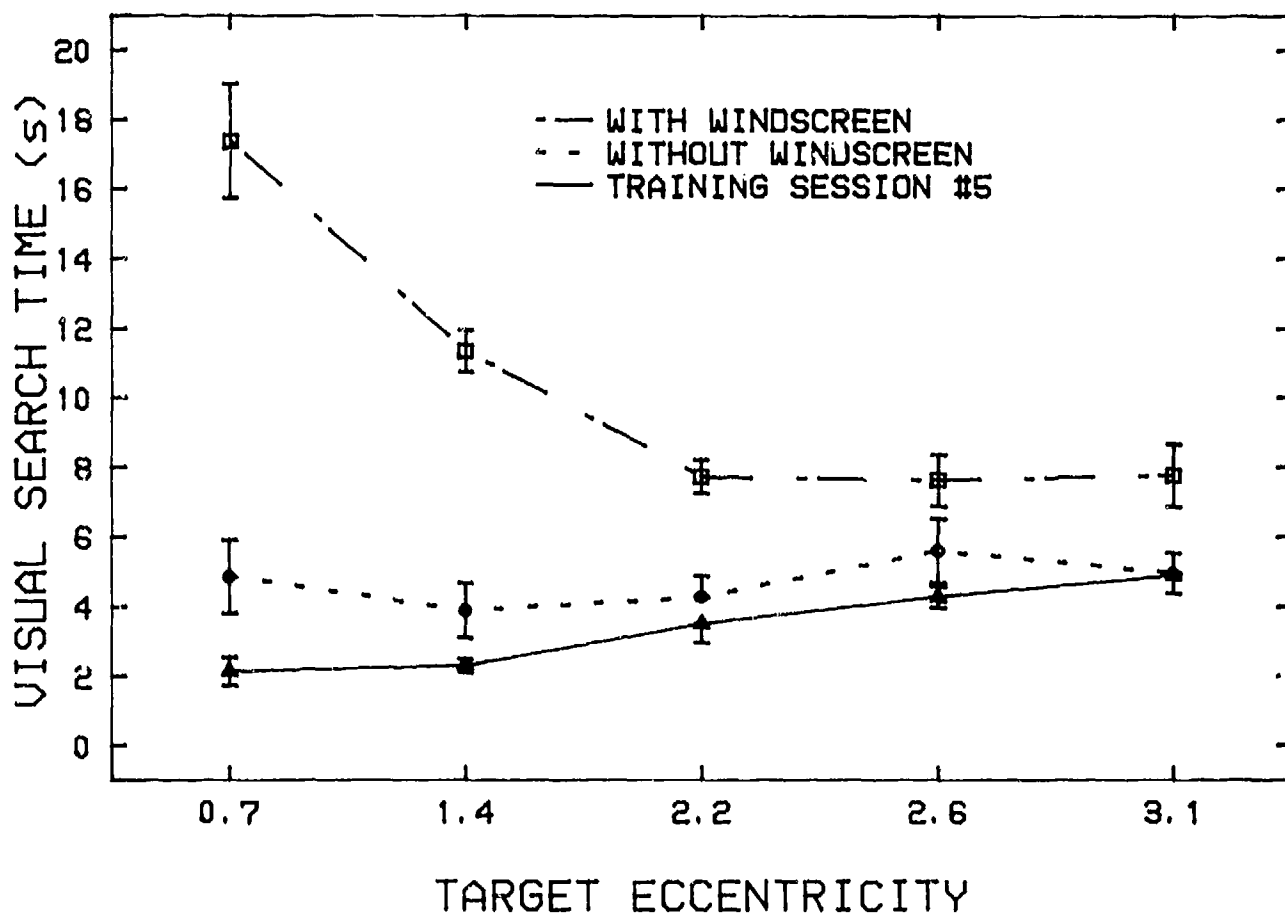


Figure 11. Mean (\pm SEM) visual search time at each target eccentricity from display center for laser exposure at $0.20 \mu\text{W}/\text{cm}^2$.